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Neutronics calculations for the ITER Collective Thomson Scattering Diagnostics

17th Meeting on Reactor Physics in the Nordic Countries
Göteborg, Sweden May 11-12, 2015

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Outline

- Introduction
- ITER project
- Experience from MCNP calculations on fission reactors utilized on fusion
- A simplified MCNP 40^{o} model for CTS
- Examples of calculations on CTS
- Shutdown dose rate calculation
- Prospective

ITER Schedule

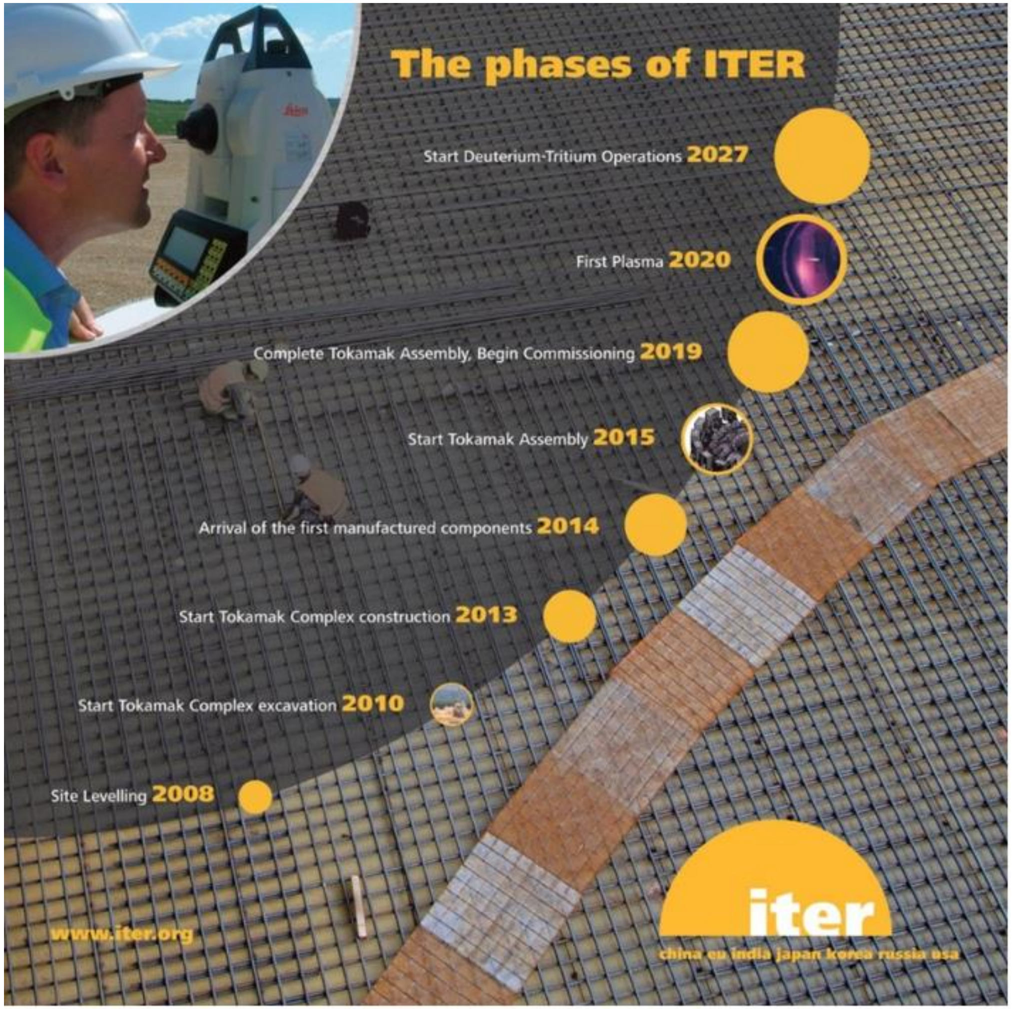
- Costs: 15 billion euro
- Start of construction 2010
- First plasma: 2020 using H as test fuel
- 2027: Q=10, 50MW in 500MW out
- Deuterium+Tritium ~ 14.1 MeV (neutrons) 3.5 MeV (alfa)
- Decommissioning 2040
- DEMO ~ 2035-2040

Overall Tokamak parameters

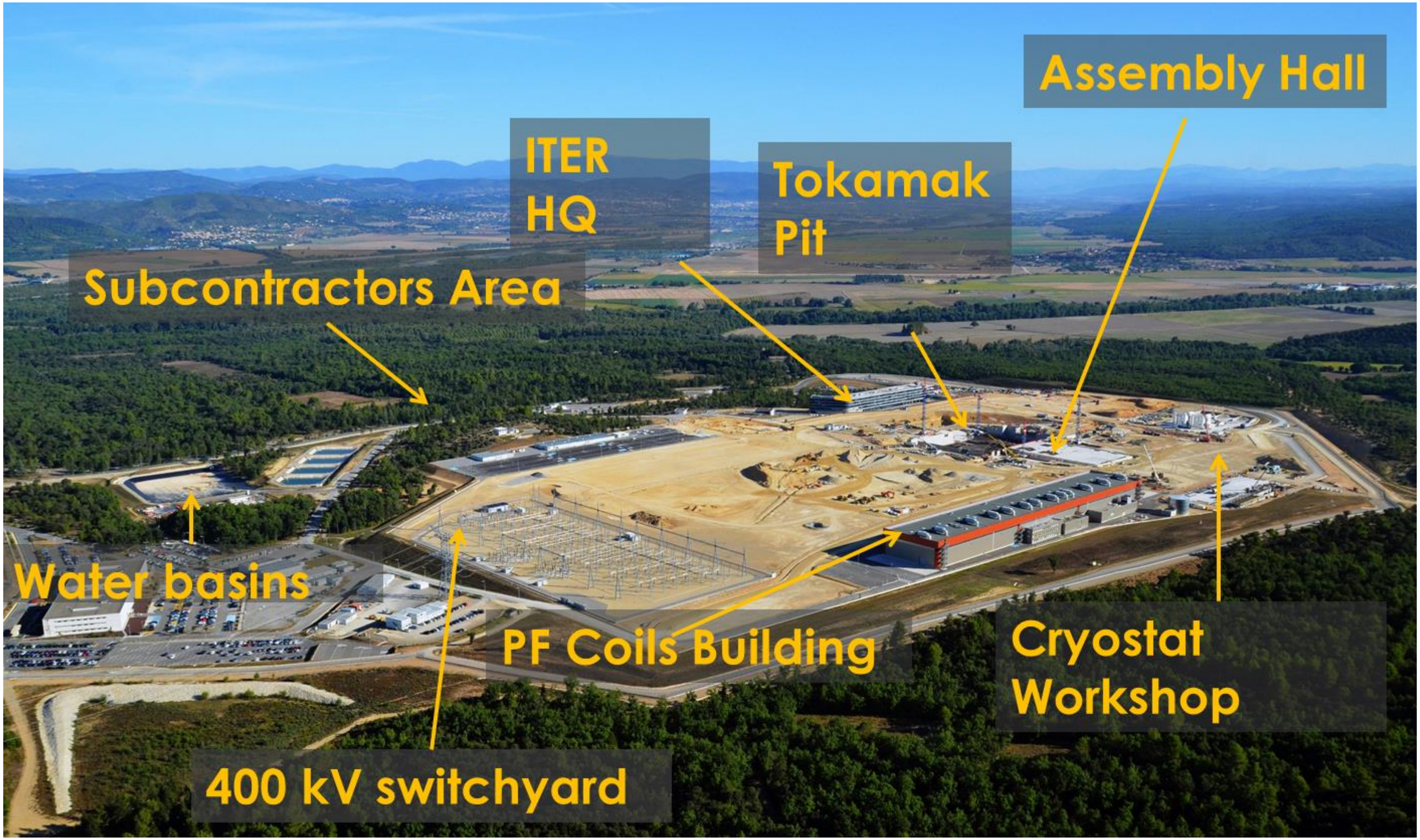
Fusion Power & Plasma	
Total fusion power	500 MW
Plasma major radius (R)	6.2 m
Plasma minor radius (a)	2.0 m
Plasma current (I_p)	15 MA (eventual 17MA Capability)
Toroidal field at 6.2 m radius (B_T)	5.3 T
Approximate Plasma Volume	$816 m^3$
Approximate Plasma Surface	$680 m^2$

Components	
Number of TF coils	18
Number of CS modules	6
Number of PF coils	6
In Vessel Coils – ELM suppression - Vertical Stabilization	ELM: 27 picture frame-type coils VS: 2 pairs of toroidal ring coils
Vacuum vessel segmentation (fabrication)	9
Divertor segmentation (Cassettes)	54
Shielding Blanket Modules	440
Ports (Lower, Equatorial, Upper)	44 (9 + 17 + 18)
Cryostat	1 assembly (4 sections)
Thermal shields	4 sub-assemblies
VVPSS	1 assembly

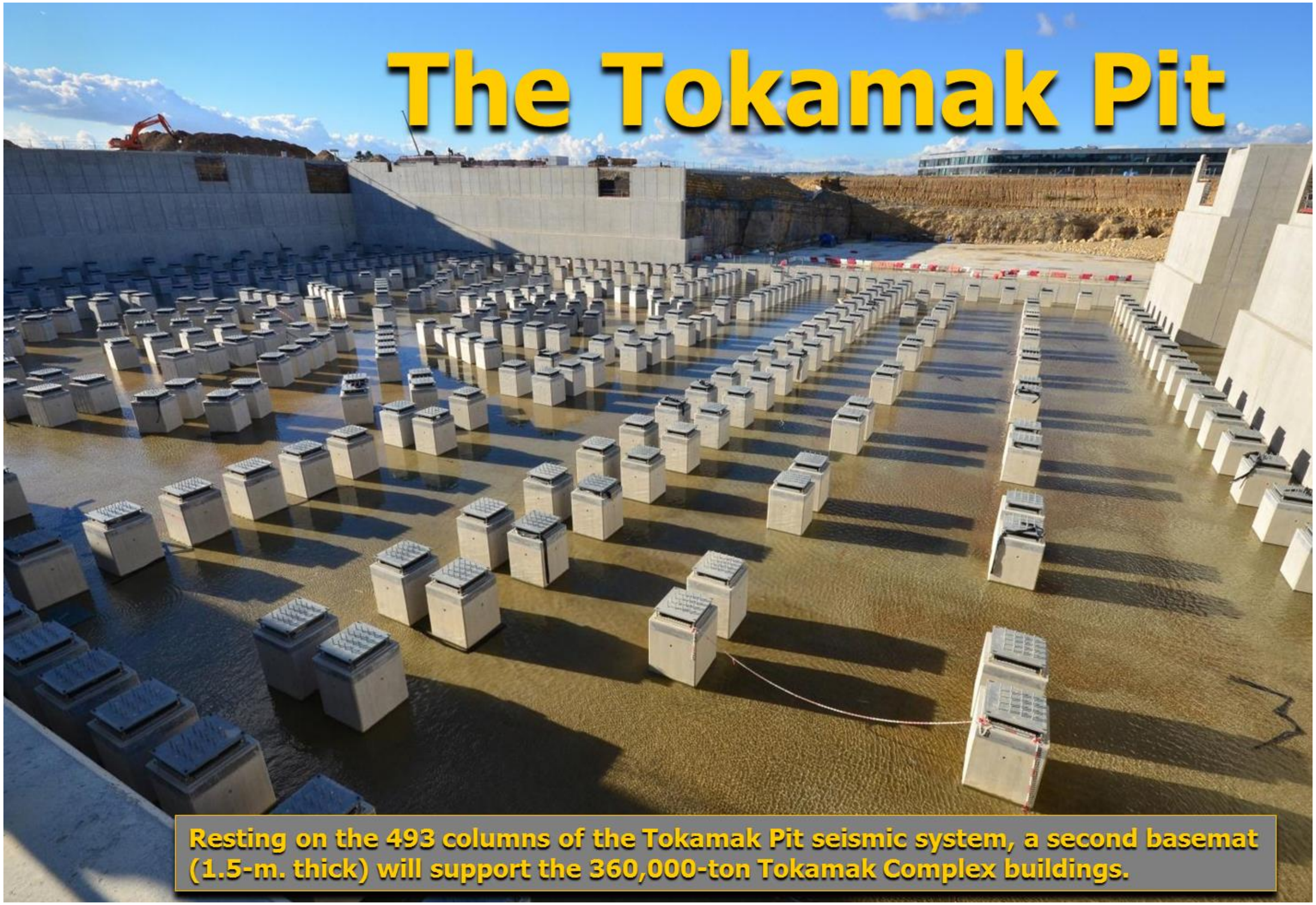
The phases of ITER



Progress on the ITER platform

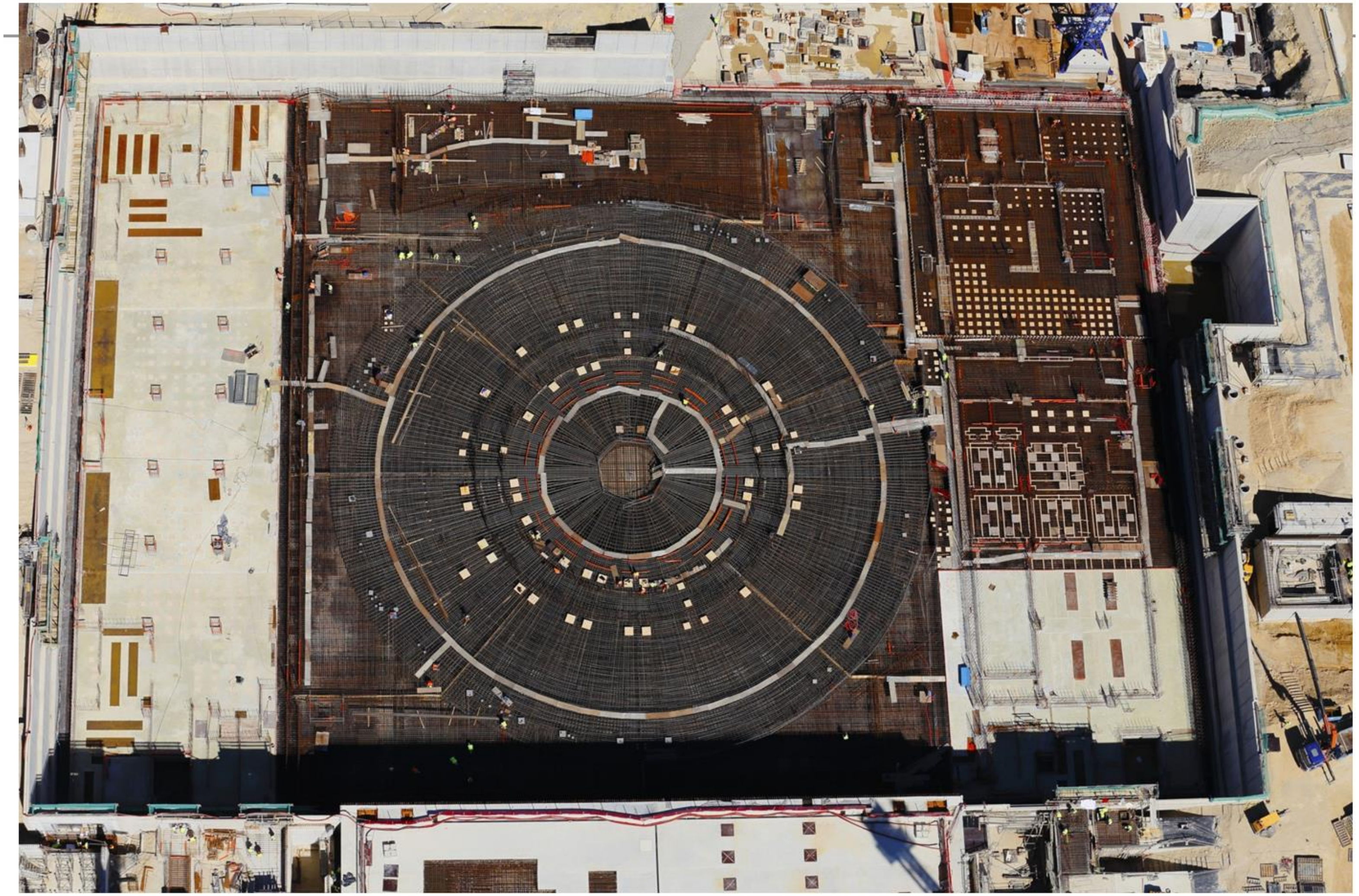


Tokamak Pit seismic system with 493 columns



Tokamak Pit

Picture taken April 30, 2014



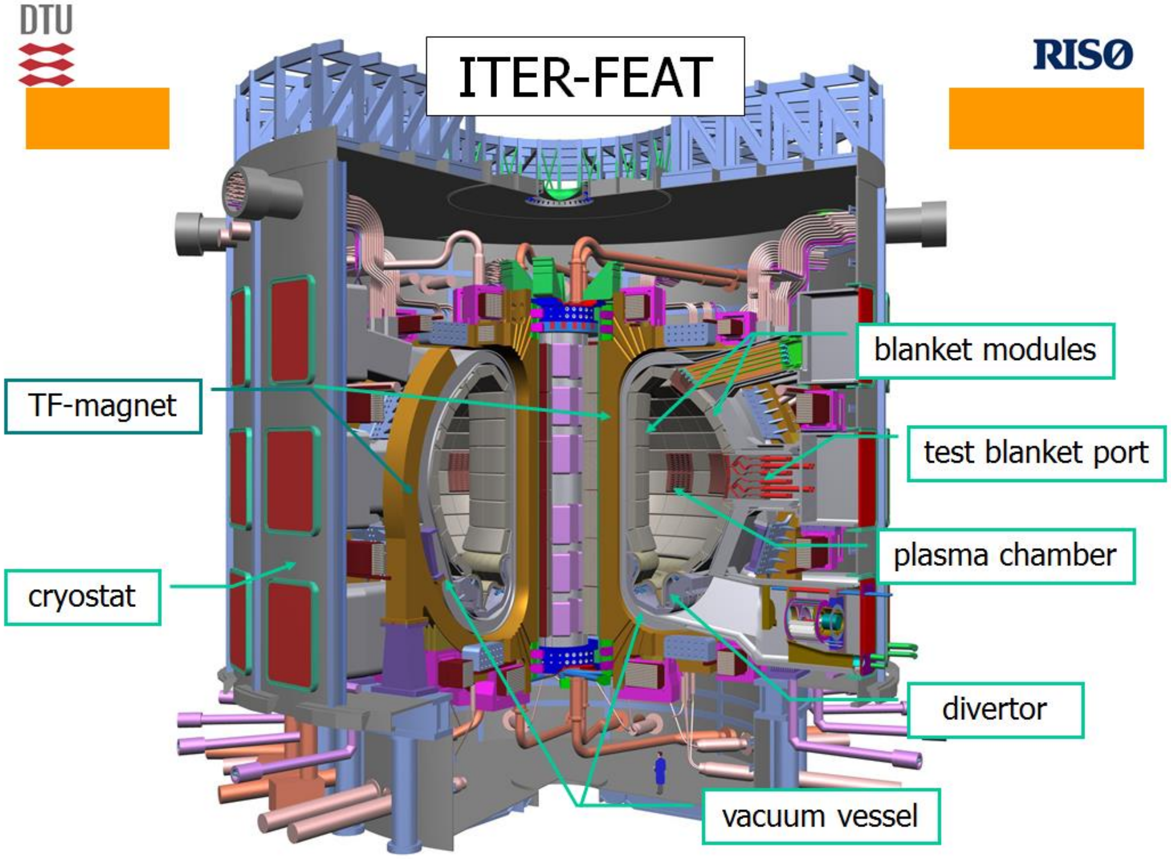
Background

- Recently F4E awarded DTU and IST to partner in the design of a Collective Thomson scattering (CTS) diagnostic for ITER, F4E-FPA-393
- The CTS diagnostic utilizes probing radiation of ~60 GHz emitted into the plasma and, using a mirror, collects the scattered radiation by an array of receivers
- Having a direct and unshielded view to the plasma, the first mirror will be subject to significant radiation and among the first tasks in the CTS design, is to determine whether the mirror will need active cooling
- In order to address this question, a simplified MCNP model of the relevant equatorial port plug #12 was developed based on the full C-lite ITER MCNP model
- The first steps toward benchmarking the simplified model to the full C-lite model have almost been completed
- Based on this, we have done the first calculations of heat-loads across the mirror

Reasons for joining ITER project

- Experience in calculation of neutron and gamma fluxes and neutron activation in fission reactors by means of the Monte Carlo code MCNP
- Local Association Euratom/Risø DTU Plasma group, need for in-house neutronics calculation capabilities for designing the Collective Thomson Scattering (CTS) diagnostics system to be installed in one of the drawers in equatorial port plug #12

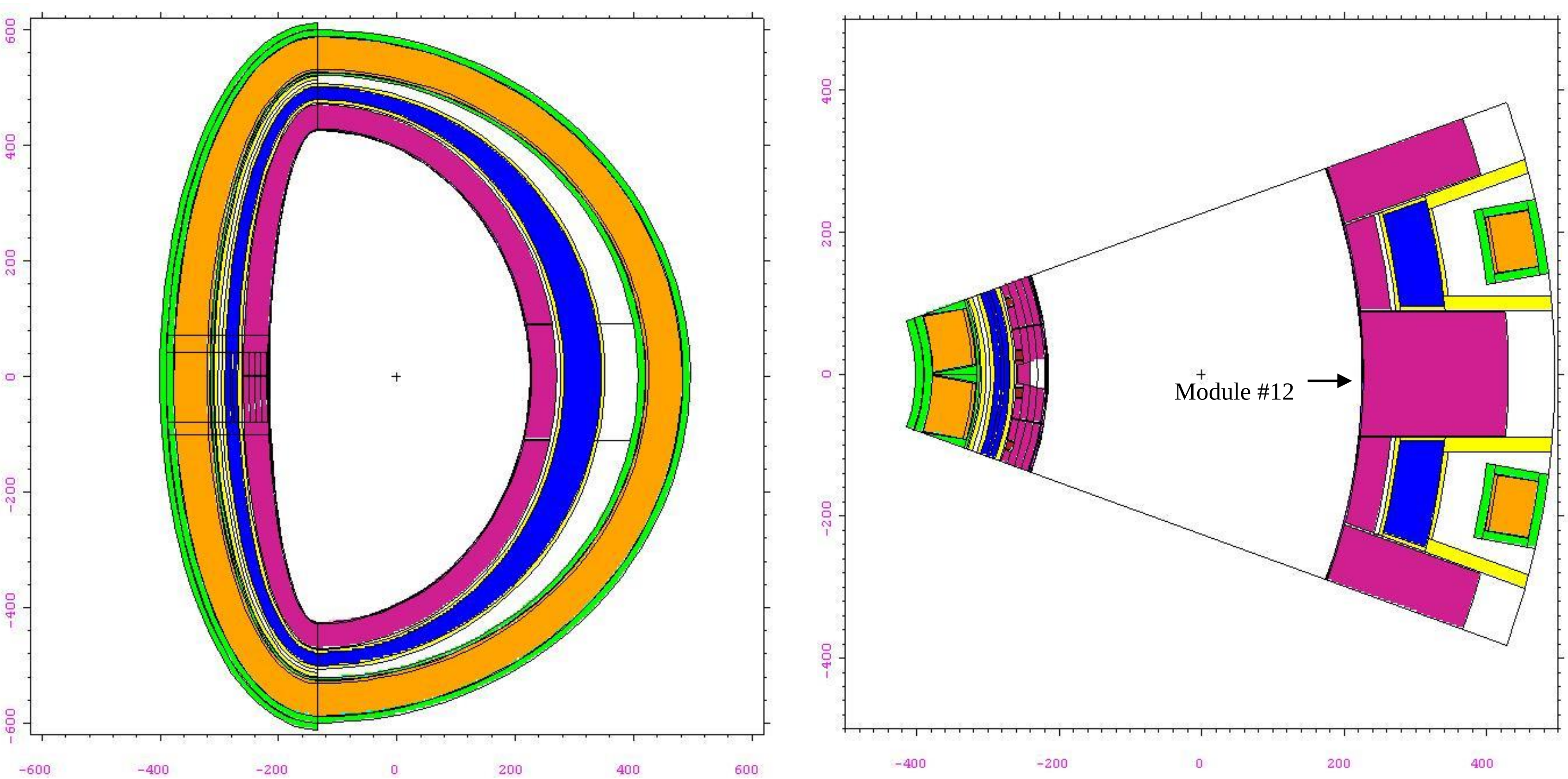
Layout of ITER machine



Status as of December 2013

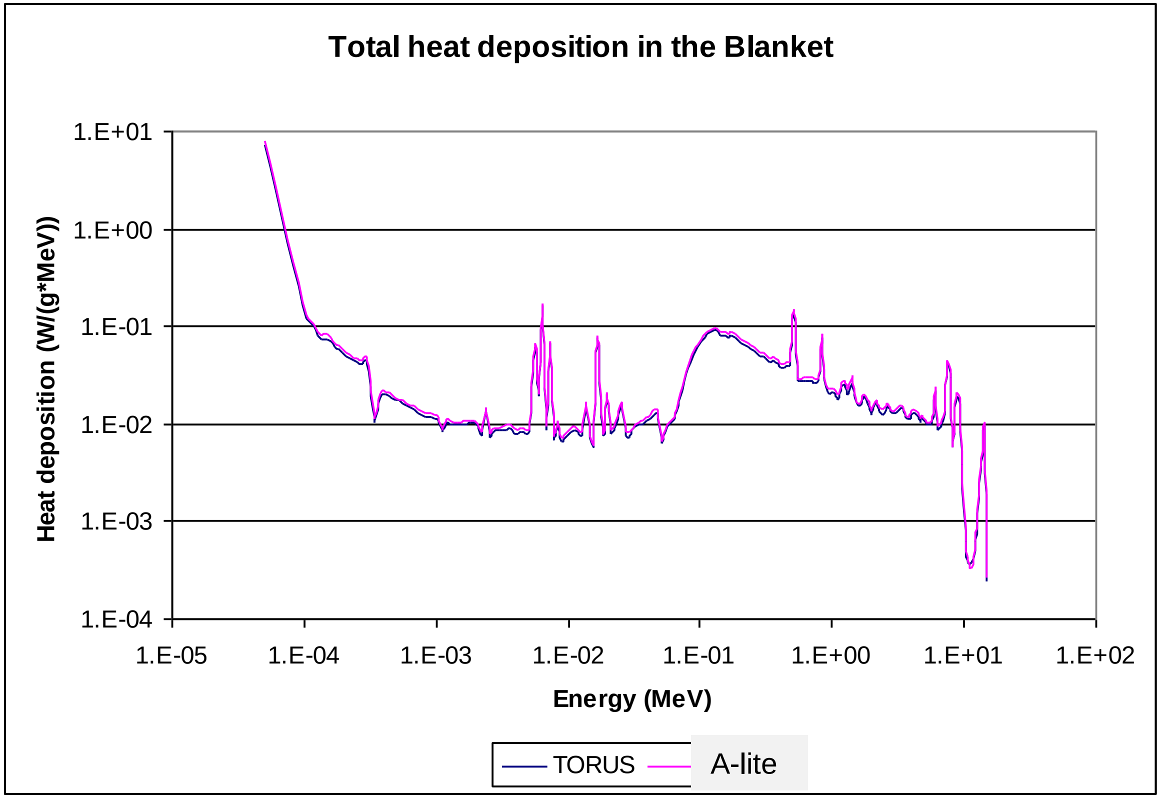
- A simplified ITER 40 degree geometry input model for MCNP-5 has been developed
- Detailed geometric description of the CTS diagnostics system
- Well suited for parametric studies
- The input model has been benchmarked against the ITER A-lite model

Examples of geometry covered and results obtained



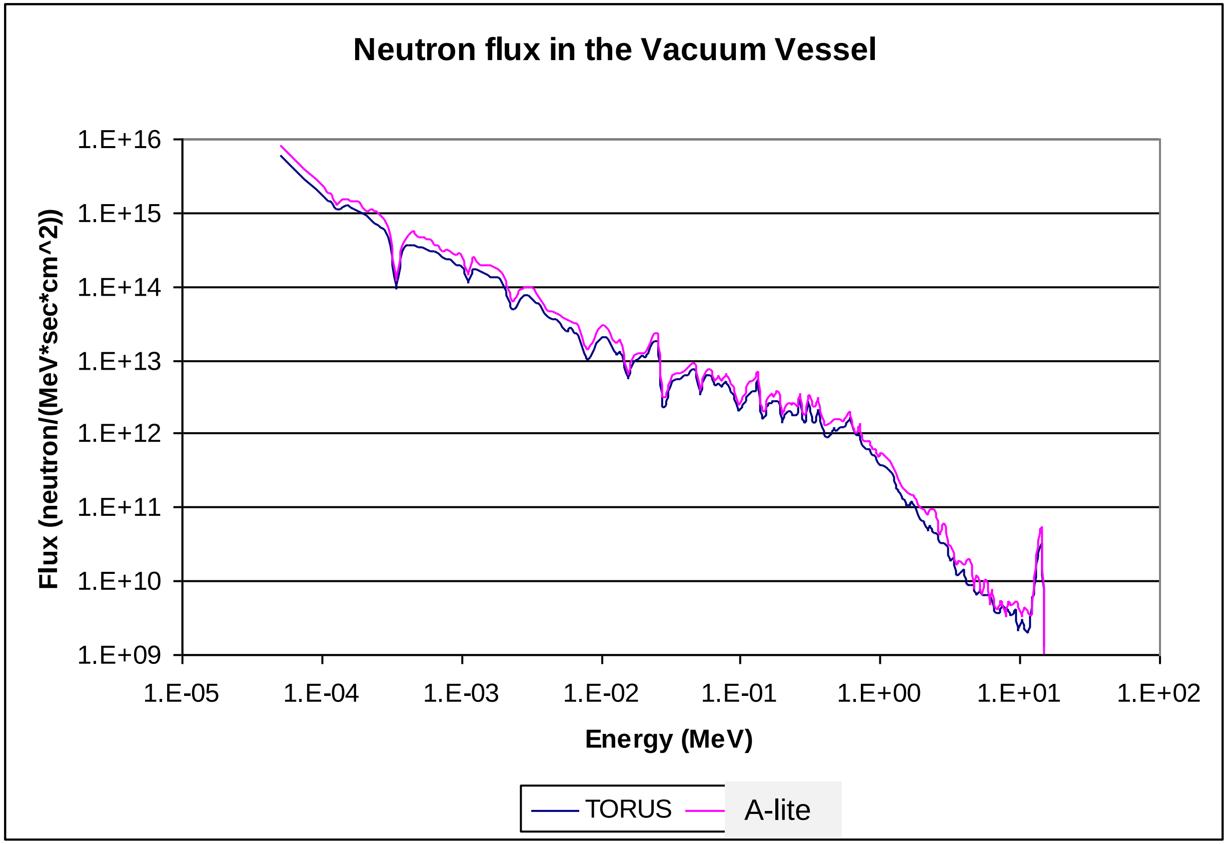
XZ and XY cross sections of the Torus 40 degrees model.

Benchmark

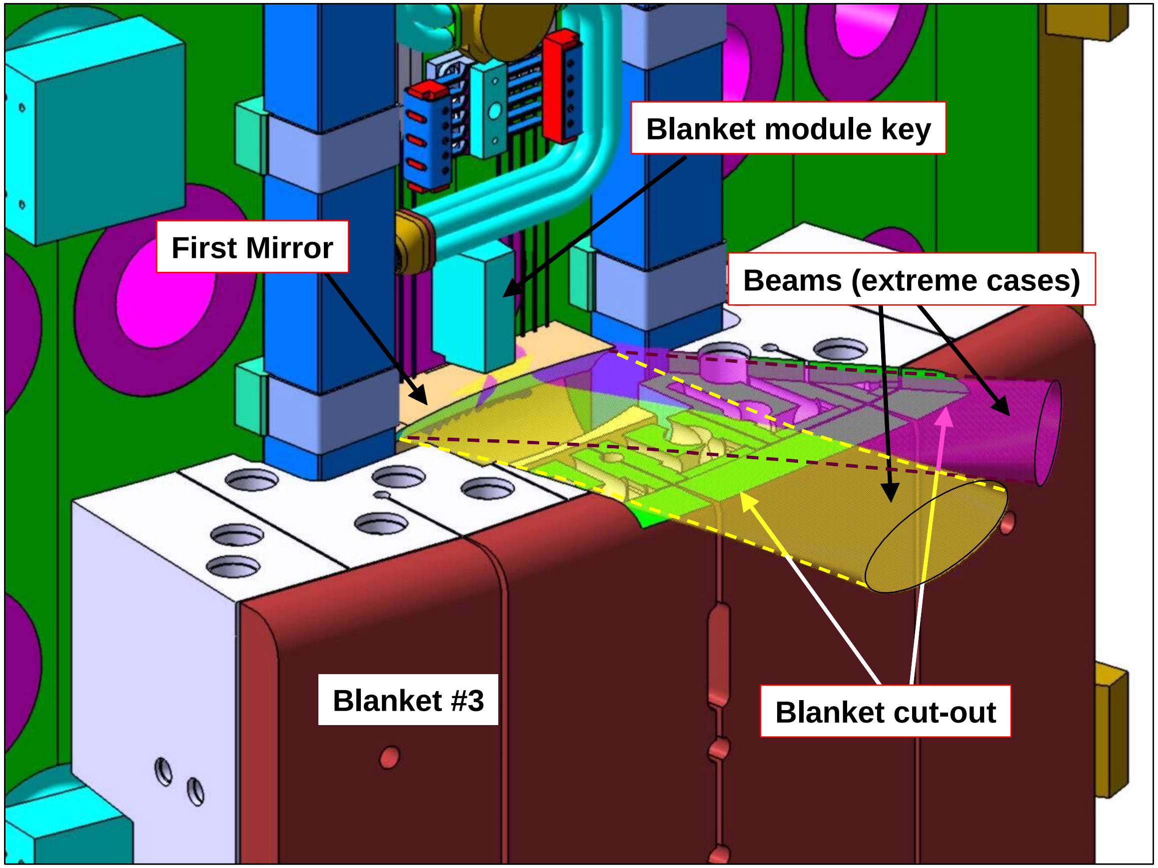


Total heat deposition in the Blanket
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
Heat deposition (W/(g*MeV))
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)
TORUS
A-lite

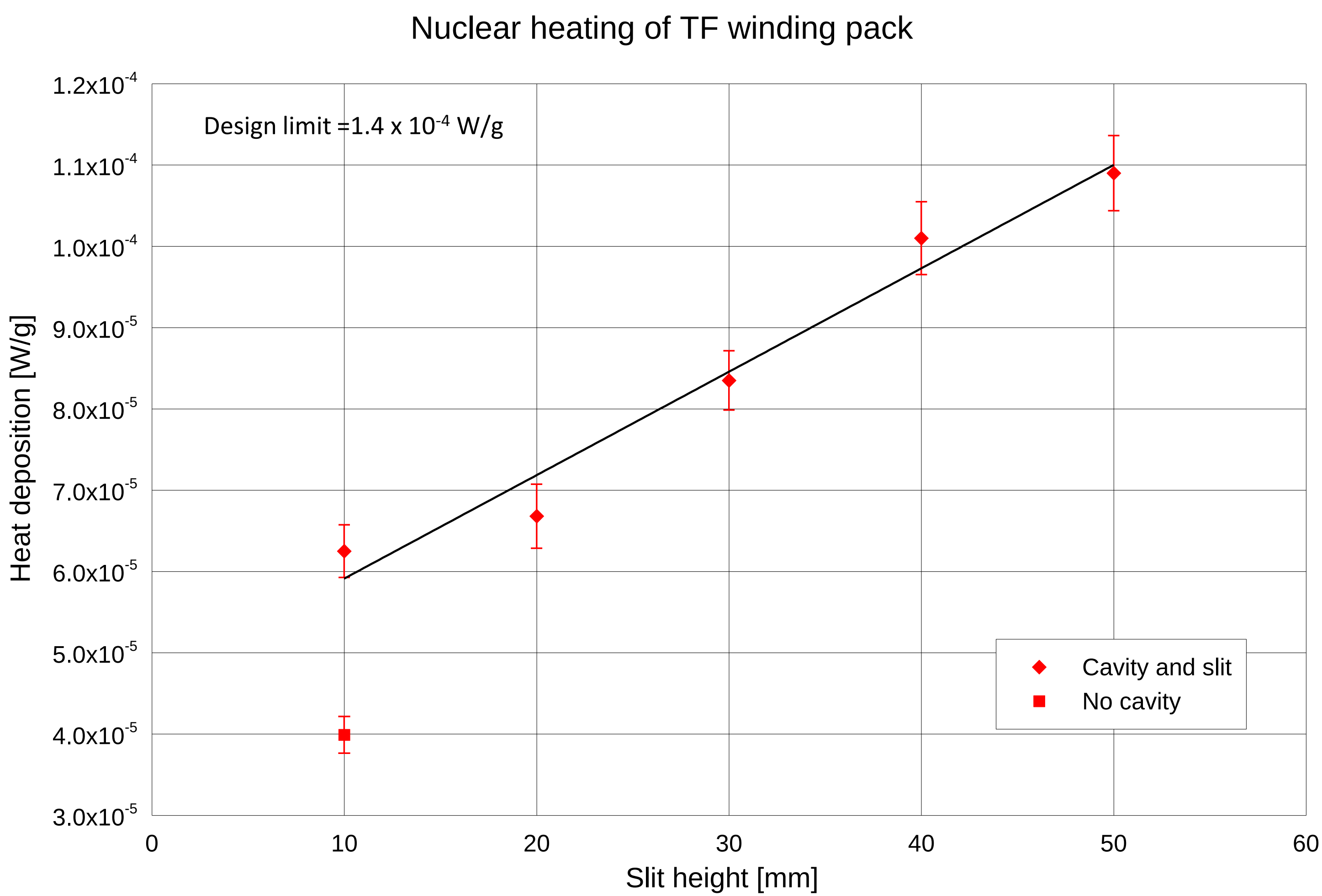
Benchmark


Neutron flux in the Vacuum Vessel
Flux (neutron/(MeV*sec*cm^2))
1.E+16
1.E+15
1.E+14
1.E+13
1.E+12
1.E+11
1.E+10
1.E+09
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)
TORUS
A-lite

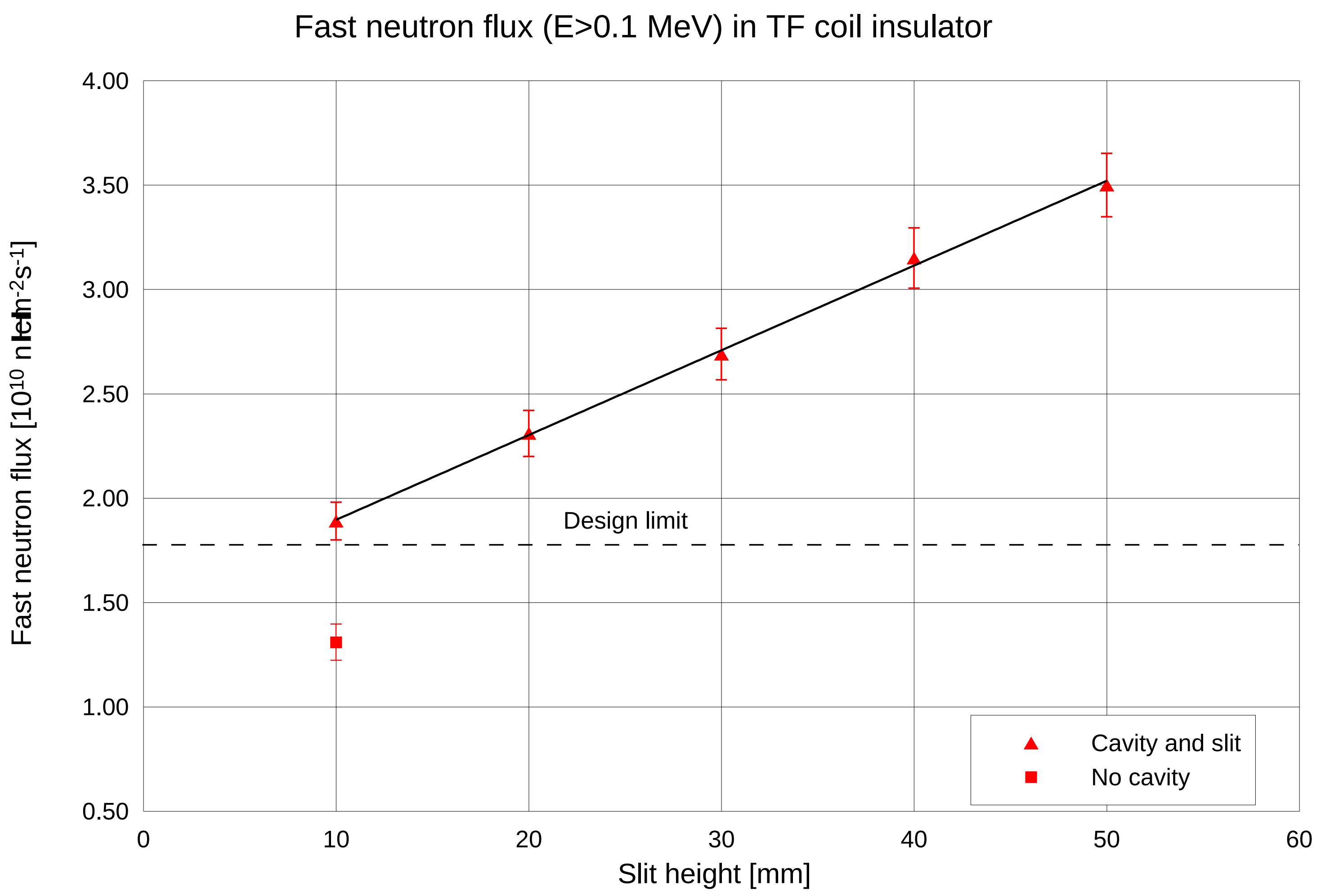
Mirror in slit



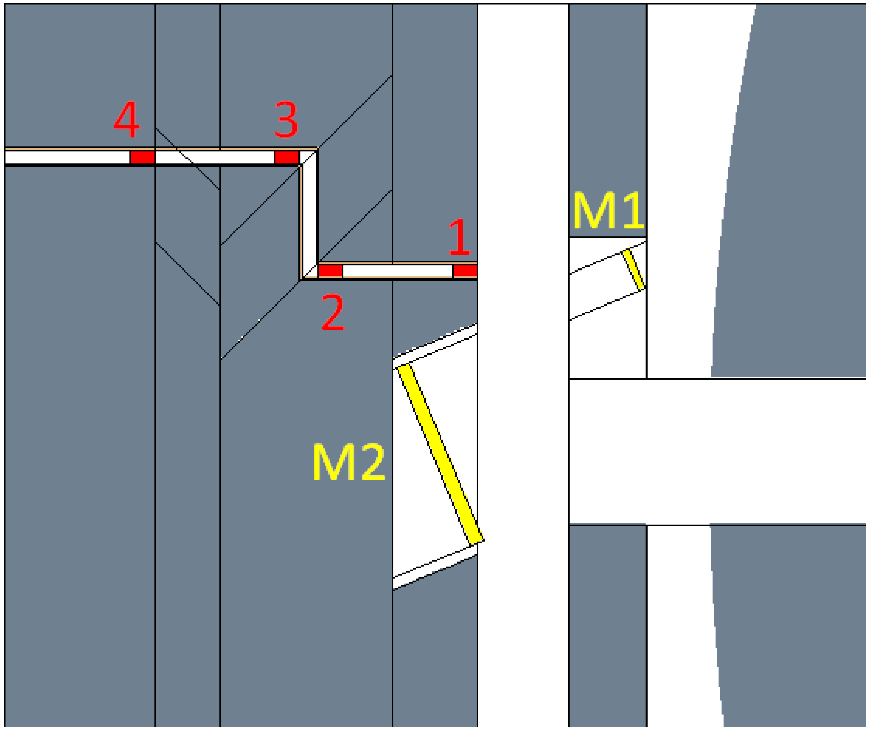
Nuclear heating of TF winding pack



Fast neutron flux in TF coil insulator (epoxy)



Examples of geometry covered and results obtained



Position of the mirrors M1 and M2 of the LF CTS system

(XZ views)

TABLE 1. Heat deposition in the mirrors of the LF CTS system.

	Photon Heat Deposition (W/g)	Neutron Heat Deposition (W/g)	Total Heat Deposition (W/g)
Mirror 1	4.95E-2 (±0.45%)	2.11E-3 (±0.98%)	5.16E-2 (±0.44%)
Mirror 2	6.00E-2 (±0.18%)	8.15E-3 (±0.48%)	6.81E-2 (±0.20%)

Mirror design of the CTS system

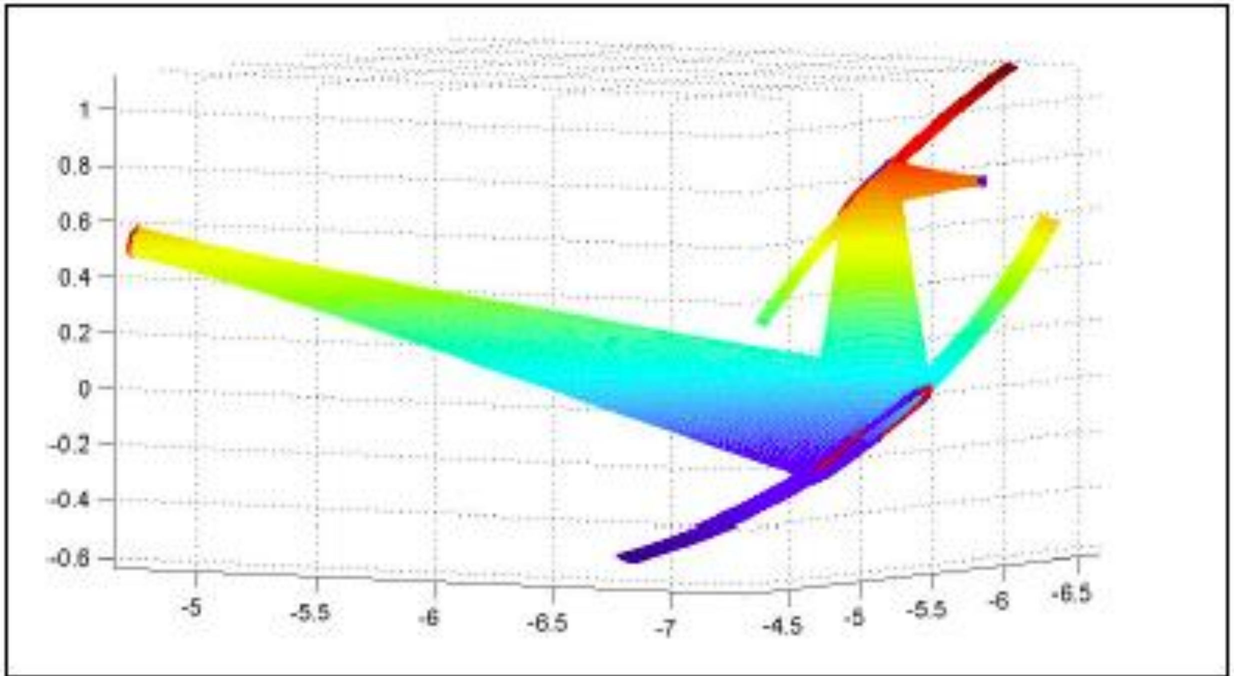


Figure 26: Modelling of the mirror shapes and the centre beam of the LFS CTS receiver

CTS launcher and receiver beams

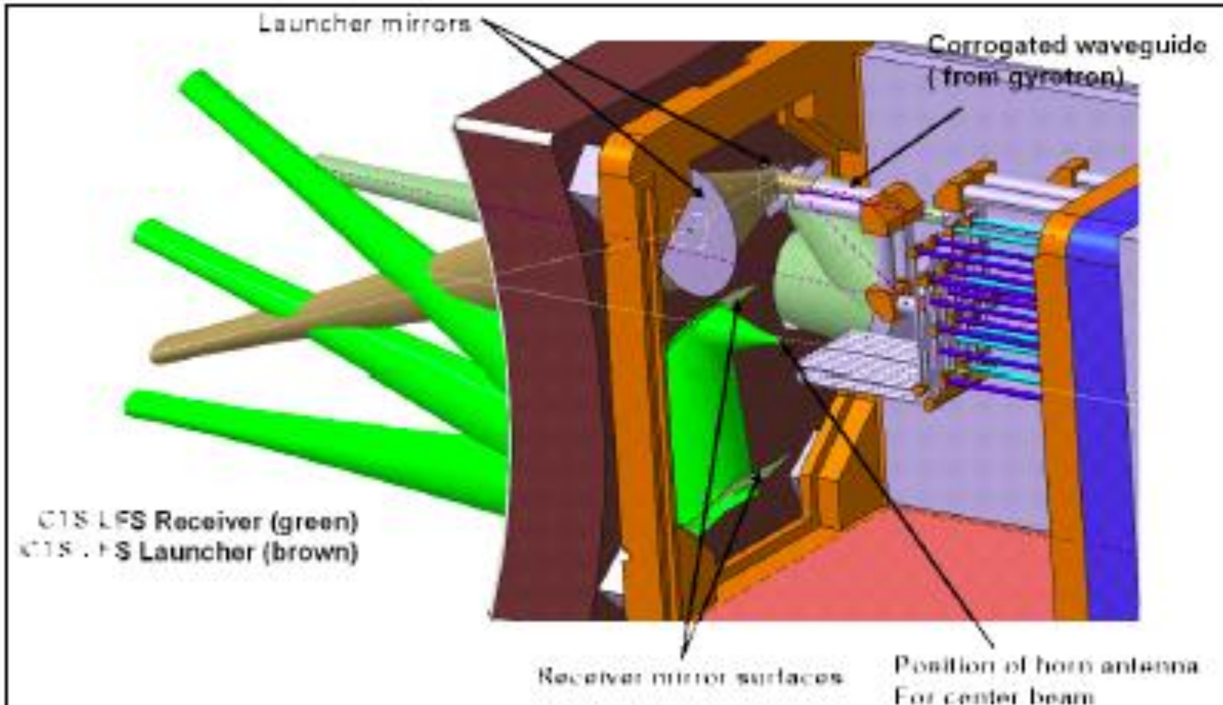
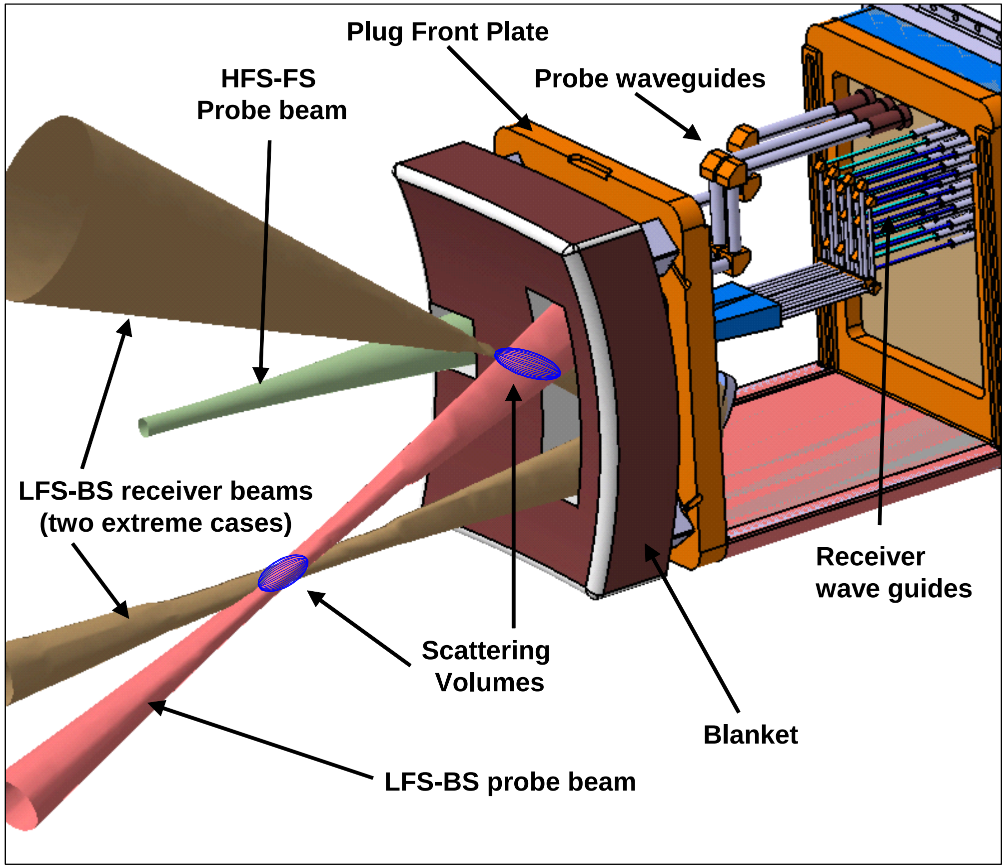
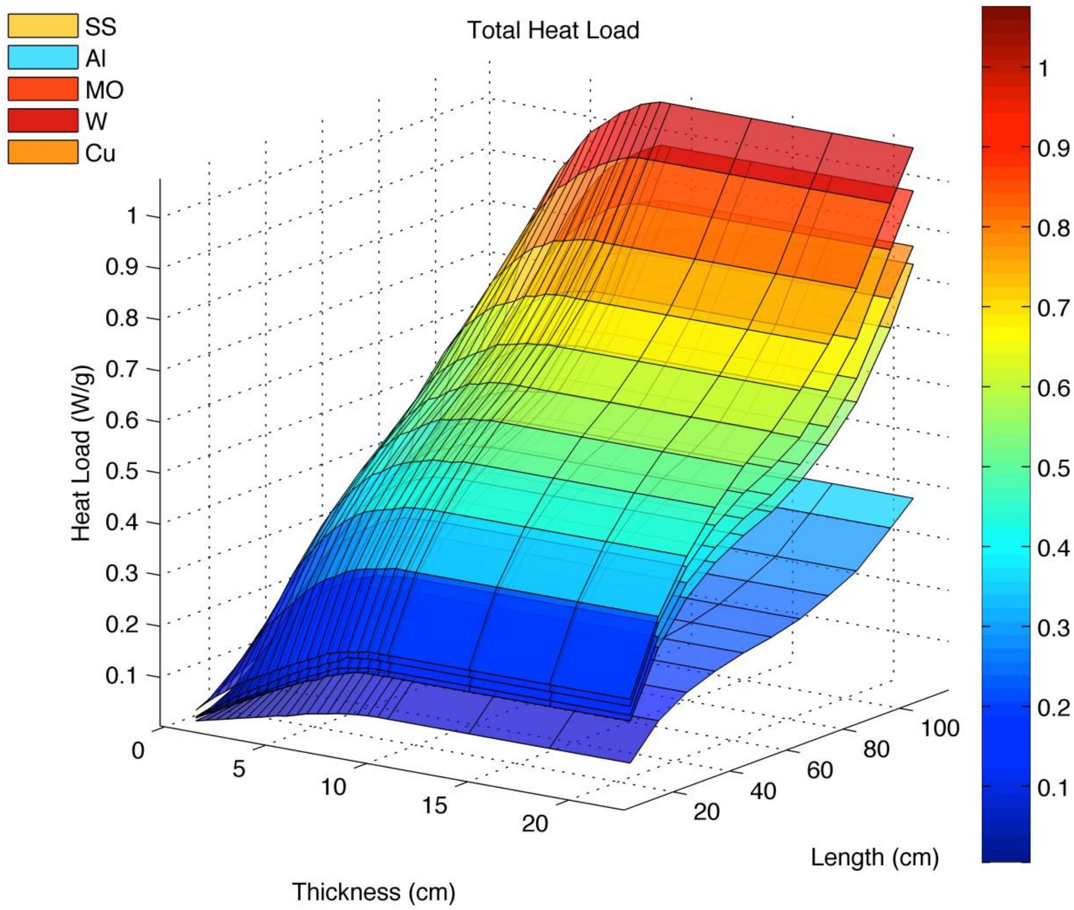


Figure 27: Equatorial port #12 on ITER with LFS CTS launcher and receiver beams, rear view

CTS equatorial port plug

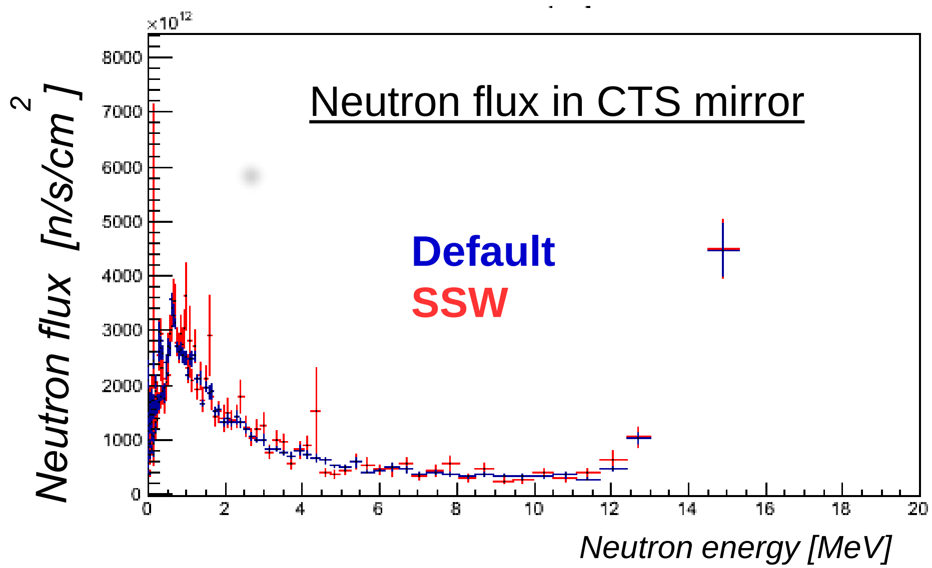


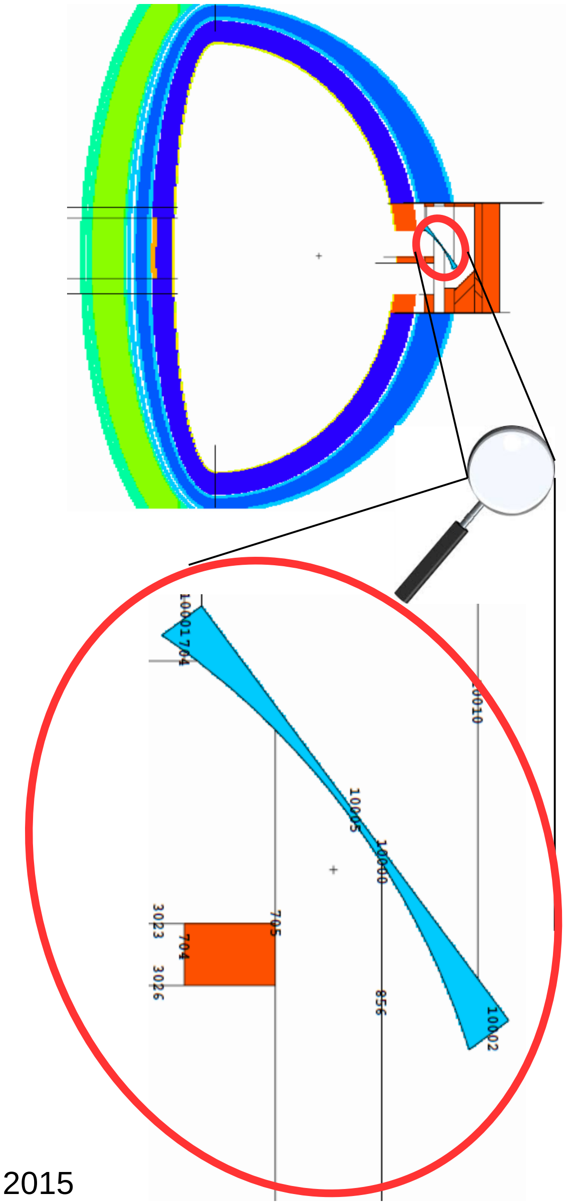
Total heat load on mirror for different material composition



Source Surface Write/Read

- MCNP feature allowing to stop a simulation at a given surface, and restart it later
- Potential to speed up series of simulations:
  - If the overall model is complicated (like C-lite)
  - If the difference between configurations are small.
- CTS mirror not in C-lite yet → test SSW/SSR on simple 40 degree model (with C-lite source discussed up till now)





- Capability to couple to ROOT analysis framework - proven useful in the design of the target-moderator-reflector system at the European Spallation Source

Dose Rate Criteria (inside bio-shield)

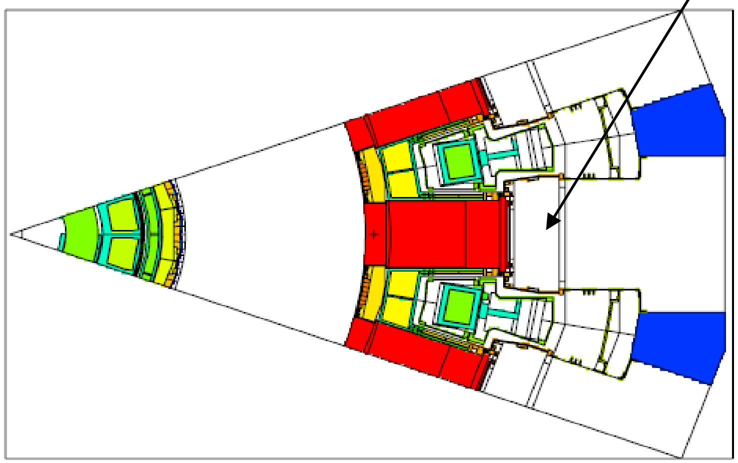
- Where planned maintenance is required the dose-rate must be less than 100µSv/hr.
- For unplanned maintenance it must be ALARA and never more than 2mSv/hr.
- Average occupational radiation exposure must be less than 500 man.mSv/yr
- Systems must be designed with ALARA in mind

Shutdown dose-rate

Activation of especially Cobalt (50%) and Tantalum (20%) in stainless steel structure cause significant nuclear heating which is problematic in terms of maintenance

ITER limits: 100 μSv/h 10 days after shutdown in areas were maintenance is expected

For the CTS this means the interspace area



Neutron attenuation through the equatorial port plug

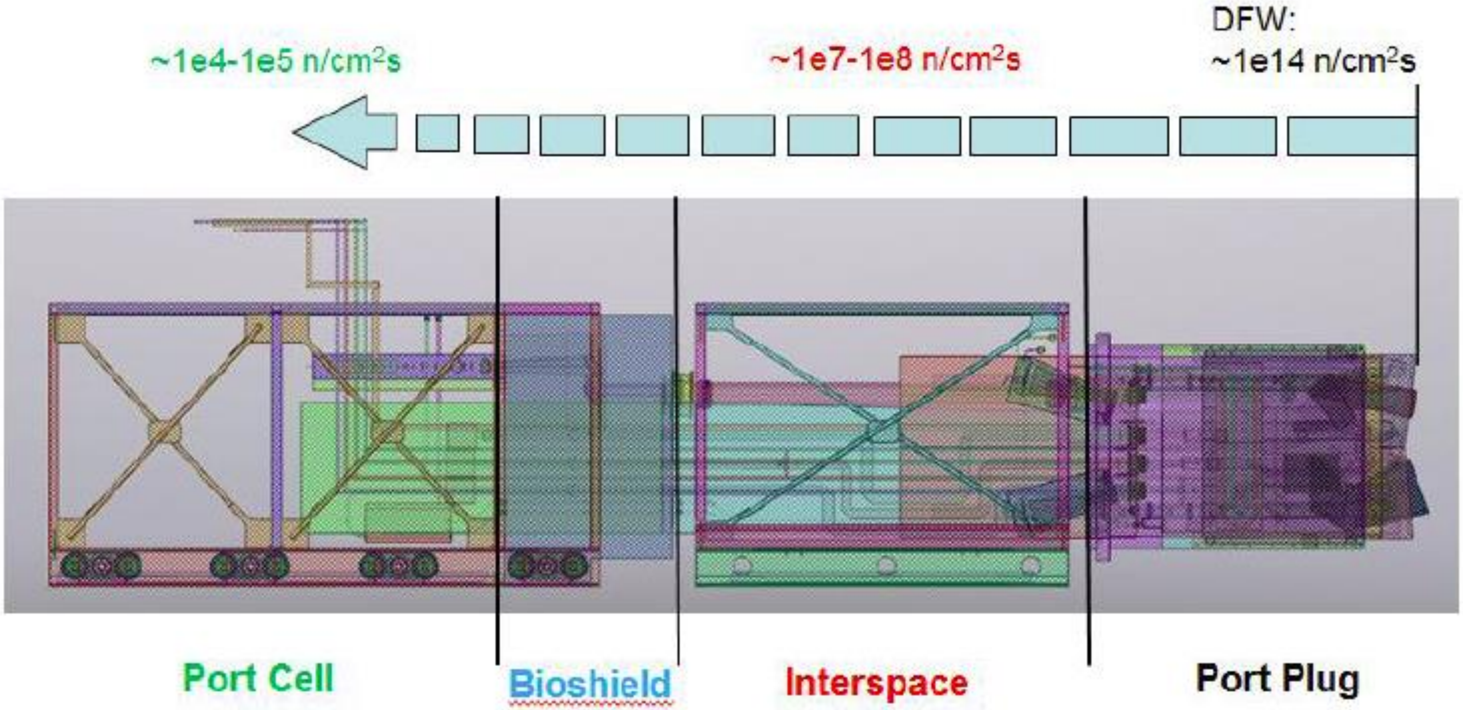


Figure 1: Orders of magnitude of neutron attenuation from the plasma to the Port Cell

Methods for Shutdown Dose Rate Calculation

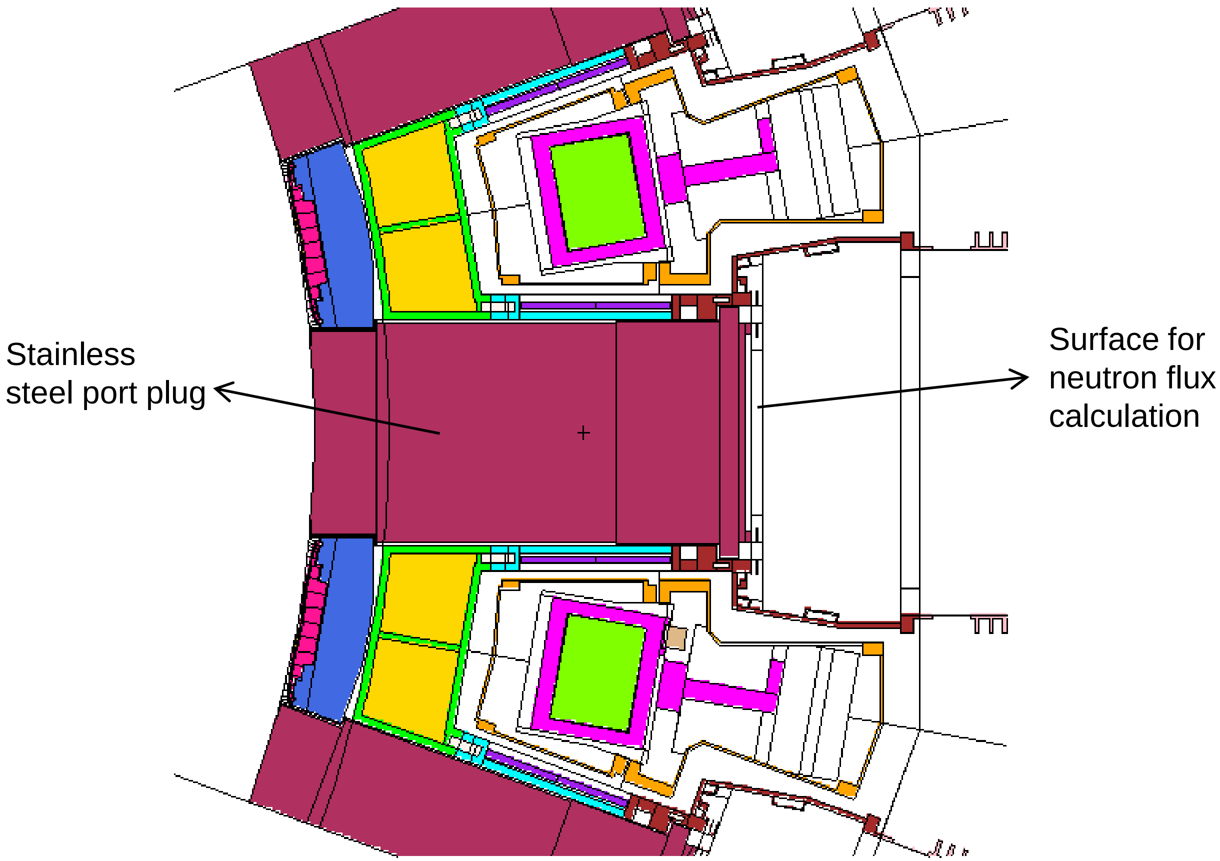
There are several methods to calculate dose rate at ITER:

- MCNP+FISPACT, MCNP6 (ACT card), "Advanced D1S method"
- In addition to these more precise methods, experience (NAR) show that for ITER a simple scaling of fast neutron (>1MeV) flux is able to predict dose-rate with a precision satisfactory for our purposes

Shutdown dose-rate calculation

- Neutron flux at entrance wall to the port interspace:
  5.94807E-13 n/cm2/(source_neutron) >1MeV
- Conversion factor (normalization in CLITE): 1.9718E19 =>
- Flux: 5.94807E-13 x 1.9718E19 n/cm2/s = 6.35E8 n/cm2/s
- Flux to shutdown-dose-rate conversions :
  1.33E-5 (micro Sv/h) / (n/cm2/s)
- Shutdown dose-rate:
  6.35E8 n/cm2/s * 1.33E-5 (micro Sv/h) / (n/cm2/s)
  = 156 micro Sv/h

Horizontal view of Equitorial Port Plug from mcnp/C-lite



Conclusion

- Even without cut outs in FDW to install any version of the CTS, the limit is exeeded (consistent with observations at other diagnostics)
- => a global solution is needed, shielding must be added. For the CTS, we can study relative changes in shut-down dose-rates using the above scaling approach

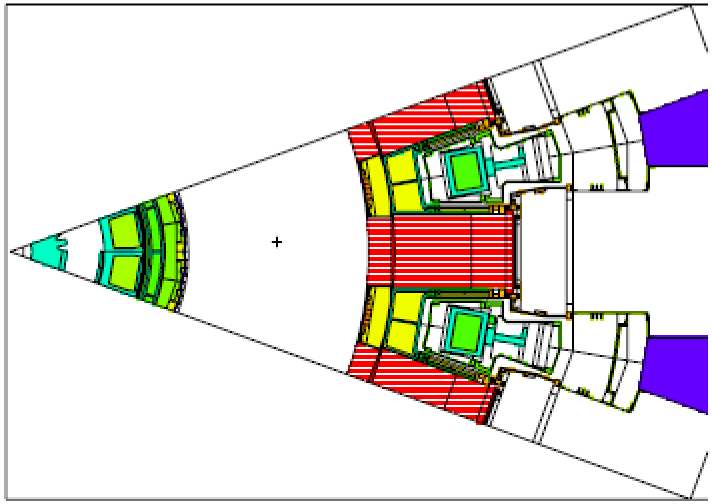
Prospective

- Further benchmarking our 40 degree model against C-lite MCNP reference model
- Further neutronics analyses of the CTS system to determine whether active cooling of the CTS mirror is needed
- Calculation of the CTS system contribution to the shutdown dose rate of EPP #12

Thanks for your attention

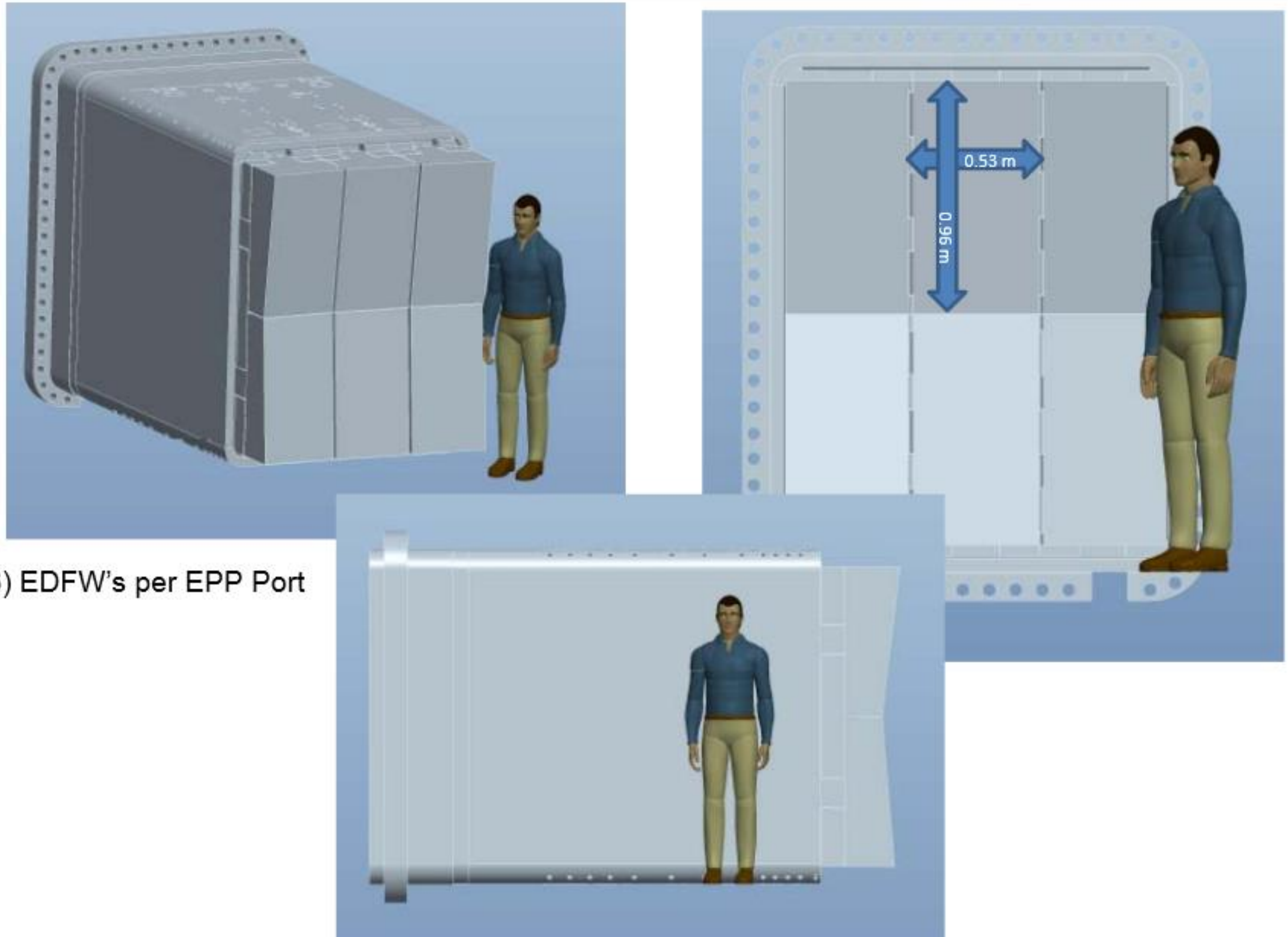
C-lite horizontal plot

```
  03/06/14 15:19:25
C-LITE VERSION 1 RELEASE 131031
 ISSUED 31/10/2013 - Halloween
 edition
probid =   03/06/14 13:57:43
basis:   XY
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
(   618.56,    22.64,    -1.38)
extent = (  1000.00,  1000.00)
```



Scale of equatorial port plug diagnostics first wall

Scale of EPP EDFW



(6) EDFW's per EPP Port

Drawers in EPP #12

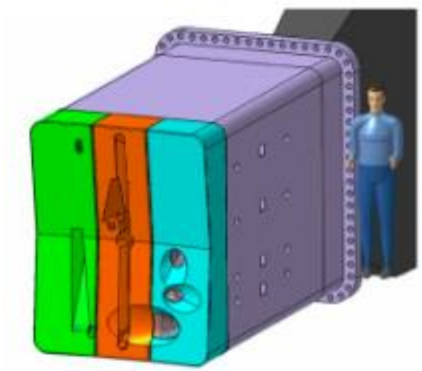


Figure 3.15 - Equatorial port plug 1 and the new drawers concept.